COST
EUROPEAN COOPERATION
IN SCIENCE & TECHNOLOGY

Brussels, 12 May 2023

COST 068/23

DECISION

Subject: Memorandum of Understanding for the implementation of the COST Action "Exploiting Plant-Microbiomes Networks and Synthetic Communities to improve Crops Fitness " (CropBiomes) CA22158

The COST Member Countries will find attached the Memorandum of Understanding for the COST Action Exploiting Plant-Microbiomes Networks and Synthetic Communities to improve Crops Fitness approved by the Committee of Senior Officials through written procedure on 12 May 2023.

MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA22158
EXPLOITING PLANT-MICROBIOMES NETWORKS AND SYNTHETIC COMMUNITIES TO IMPROVE CROPS FITNESS (CropBiomes)

The COST Members through the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action, referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any document amending or replacing them.

The main aim and objective of the Action is to coordinate the available knowledge on plant´s microbiome assembly, and its potential to increase crop holobiome resistance to drought and heat, or diseases. It also aims to explore advances in engineering microbiomes, and aid in management and policy tools to improve the resilience of crop plants. This will be achieved through the specific objectives detailed in the Technical Annex.

The present MoU enters into force on the date of the approval of the COST Action by the CSO.

TECHNICAL ANNEX

OVERVIEW

Summary

Europe faces an increased frequency of drought and heat waves and the appearance of new diseases. It's urgent to develop alternatives to current agricultural systems that highly depend on agrochemicals and water. CropBiomes grounds on the urgent need for transition to Sustainable Agriculture ensuring food Security and Safety, aligned with both GreenDeal and "Farm-to-Fork" strategy. CropBiomes will gather European experts to coordinate and develop knowledge on crop microbiomes (and holobiomes) for application in precision sustainable agriculture. It will exploit technological advances (e.g., engineered microbiomes) to selectively improve the holobiomes' resistance to specific environments like drought and diseases. The knowledge of the crop as a "Holobiont" responsible for its fitness, as well as the technologies to explore "hub" taxa to potentiate community-scale networks, and the holobiome fitness, remain yet underexplored in agriculture.

The networking will be transdisciplinary and balanced (e.g., gender, researchers-career, countries) and intersectoral, structured to generate long-lasting impact. The four Working Groups will go beyond the current state of the art in crop microbiomes. It will define new concepts on topics like plant-microbiomes' diversity, distribution, eco-evolution, crosstalks, and the microbiomes/holobiomes dynamics and crosstalks under specific environments like soilless systems and environmental stressors (drought/heat, pathogens). Finally, the Action will explore the plant microbiome as a source of beneficial associations of microorganisms, and exploit technologies for engineering the microbiomes (through Synthetic Communities). The CropBiomes will gather senior and early researchers, and different stakeholders and contribute to the competitiveness of Europe in this field.

Areas of Expertise Relevant for the Action	Keywords
● Agriculture, Forestry, and Fisheries: Agriculture related to crop production, soil biology and cultivation, applied plant biology, crop protection ● Agriculture, Forestry, and Fisheries: Microbiology ● Biological sciences: Plant biology, Botany ● Agriculture, Forestry, and Fisheries: Sustainable Agriculture	● Crop Holobiont ● Crop Microbiome ● Environmental Stress ● Pathogens and Plant Disease Control ● Precision Sustainable Agriculture

Specific Objectives

To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

Research Coordination

- To develop an understanding at the molecular level of assemblies and signaling regulating phytobionts.
- To develop understanding (theoretical vs experimental achievements), regarding "keystone microorganisms" to improve microbiome assemblies under different cropping systems
- To develop an understanding (theoretical vs experimental achievements) on the interference of abiotic stress (heat and drought) and biotic stress (e.g., pathogens) on microbiome associations, and exploit how keystone microorganisms (e.g., PGPs and BCAs) improve crop performance/tolerance.
- To engineer microbial communities for successfully improving holobiont fitness.
- To develop databases on plant microbiomes, and tools to make them (as much as possible) of wide Open Access.
- To provide inputs to stakeholders for solutions for a precision 3S-Agriculture.

Capacity Building

- To stimulate long-lasting transdisciplinary research network on plant microbiomes, with a joint R&D&I agenda
- To involve long-term interactive balanced networks.

TECHNICAL ANNEX

1. S&T EXCELLENCE

1.1. SOUNDNESS OF THE CHALLENGE

1.1.1. DESCRIPTION OF THE STATE OF THE ART

Plant-Holobionts are a new Platform for Precision Agriculture: Research and knowledge sharing on plant-microbial networks is gaining importance in agriculture and food science. Plants have co-evolved with their associated microbiome, adapting to environmental conditions and ensuring the survival and fitness of the entire holobiome (Rodriguez et al. 2020; Lyu et al. 2021). Plant microbial communities, despite being different from each other in the rhizosphere, phyllosphere, and endosphere, integrate a communication network in the so-called "holobiont" (the host assemblage with various species surrounding it, which together form an ecological unit) (Berg et al. 2020; 2021). The microbiome populations may establish negative, neutral, or positive interactions among them, and with the host. Interesting examples are the pathobionts, with (co)occurring pathogen(s) influencing the microbial community and the plant immune response. Contrarily, beneficial microbes modulate the holobiome by acting, e.g., as plant growth promoters (PGPs) (e.g., Lyu et al. 2021, Costa-Santos et al. 2021), or as microbial biological control agents (MBCA). These may act as antagonists against pathogens, or elicit plant defenses (e.g., Keshavarz-Tohid et al. 2017, Besset-Manzoni et al. 2019). The pivotal importance of the plant's microbiome to potentiate crops' fitness is neglected in the current agriculture systems that are highly grounded on (i) agrochemicals that disturb the microbial community; (ii) conventional commercial inoculants that are usually composed of a single-beneficial strain (undervaluing local-strains); (iii) genetically improved crops toward yield (with high water/fertilizers inputs). These improved cultivars have, however, reduced the selection pressure to form beneficial microbial interactions (de Souza et al. 2020, Clouse and Wagner 2021). Compared with wild varieties, besides having a poorer microbiome diversity, modern cultivars also have lost some genetic features required for recruiting and managing specific microorganisms (Perez-Jaramilho et al. 2016). Altogether, these factors lead to the typical microbiota signature in the Anthropocene (Berg and Cernava 2022), causing increased outbreaks and yield losses. On other hand, rich microbial communities also enrich microbe-microbe interactions and potentiate the range of functions available to plant hosts, increasing pathogen protection, nutrient acquisition, phytohormone production, and stress tolerance (Barnes and Tringe 2022, Olmo et al. 2022).

Unveiling molecular dynamics in Plant-microbiomes assembly and communication: Understanding how microbiomes influence the crop's life cycle and fitness (e.g., water/nutrient cycling) and how global change drivers disrupt this network is pivotal for a systemic understanding of the crop as a holobiont. The MultiOmics technologies currently generate an enormous amount of complementary data, toward deciphering genetic and molecular mechanisms underlying the functional assembly of plant microbiomes. MultiOmics-based tools might help increase crop fitness and resistance by precisely manipulating its associated microbiome. Metadata integration also allows researchers to map the key pathways in the crop-holobiont that are up/down-regulated by environmental drivers. It also may provide insights into the crop-microbiome recruitment mechanisms. Mapping the holobiont networking is at its early stage, but annotated gene catalogs aid in sequencing of reads from metagenomes and metatranscriptomes, and facilitate the discovery of new gene functions and gene variants (Delgado and Andersson 2022). Other breakthrough knowledge deals with the microbiome influencing the crop epigenetics, namely DNA methylation. Epigenomics will unveil breakthrough questions about the holobiome "memory" (Corbin et al. 2020; Chen et al. 2022). For example, PGPs modulated DNA methylation and epigenetic processes (involved in crop traits), which persisted even after the removal of the inoculum, raising important questions about holobiome signaling.

Abiotic challenges directly and indirectly affect crops' performances and productivity, compromising global food security. Selective pressure promoting native beneficial microbiomes represents a remarkable feature to improve plant resistance and to counteract the negative effects of current

intensive agricultural practices and **climate change** (Rodriguez and Duran 2020, Barnes and Tringe 2022). However, our knowledge about the mechanisms that govern microbe-microbe and microbe-plant interactions under climate change (drought, heat waves, etc) is scarce and far from being used in precision agriculture (e.g., Sharma et al. 2022). It is well known that climate change drivers influence plant physiology, like photosynthesis, water use efficiency (WUE), or redox status. However, their influence on the phytobiome assembly (e.g., biofilm communities, molecular signaling), and processes leading to eventual dysbiosis remain unknown (de Souza et al. 2020, Barnes and Tringe 2022).
A similar knowledge gap regards the influence of new cropping systems as **hydroponics, and aeroponics** (like vertical farming), on the assemblies and dynamics of the phytobiome (Lobanov et al. 2022). It is highly expectable that some beneficial PGPs increase crops' fitness in hydroponic/aeroponic systems with fewer energy requirements.

Plant diseases may be related to microbiome dysbiosis and pathogenic consortia dynamics that negatively affect holobiome homeostasis. Today's plant pathology has to move from the *one pathogen–one disease hypothesis* to the pathobionts paradigm. Pathogens disrupt the plant's innate immune system (Ji et al 2022). Dysbiosis may also be caused by changes in the abundance and function of those microbial hub species that contribute to the crop's immunity system. Some tactics used by pathogens to overcome host defenses include, but are not limited to, hijacking, evading, or disrupting hormonal signaling pathways and crosstalk (Kazan and Lyons 2014). Recent data also show that diseased plants, while more susceptible to colonization by other pathogens, may recruit potential beneficial bacteria, thus enriching their microbial community with "hub" taxa to positively control the abundance/assembly of other taxa. Interestingly, these diseased plants' also show shifts regarding e.g., increased transcripts for ROS detoxification, and plant-microbiome signaling pathways (Gao et al 2021).

The Holobiont as a Potential Target for Crop-Improvement
Conventional breeding approaches consider the crop as a single species. Given the role of the holobiont as responsible for the crop's fitness, the conventional "breeding" concept might also be broadened to also include the improvement strategies targeting the holobiont, for resistance to global warming, drought, or pests and pathogens, through the incorporation of stable microbial beneficial functions (Kusstatscher et al. 2021). Since several epigenetic traits are also related to the microbiome and epigenetic mechanisms are a source of variability (Corbin et al 2020), this approach gains additional strength for crop improvement, in the "holobiont" concept. Breakthrough concepts thus emerge:

A) Identifying "disease-preventing keystone microorganisms" in plant microbiomes, and optimizing the conditions for their application: The development of PGP/MBCA systems depends on (i) identifying present keystone microorganisms in plant microbiomes (Cernava and Berg 2022), like PGP and MBCA; (ii) optimize their production at a high level, and formulation to improve their efficiency; and (iii) develop efficient delivery systems that provide a competitive advantage to this PGP/MBCA over available solutions. Thus, the efficiency of selected keystone microorganisms, also involves protocols for their mass production, formulation/stabilization (e.g., during storage), and application.

B) Microbiomes Engineering and SynComs: Synthetic Microbial Communities (SynComs) are consortia (of variable size and complexity) of microorganisms designed to mimic the structure and functions of the microbiome in natural conditions. The potential of SynComs in agriculture is receiving a great deal of interest. By adding, removing, or replacing microorganisms in a SynCom, the influence of environmental factors, and of each microbial member can be investigated (Vorholt et al. 2017), and the beneficial networks may be increased. Manipulating SynComs implies having large datasets on candidate isolates, and that those synergic interactions established in the SynCom persist with time (Herrera-Paredes et al 2018). Emerging assays show that SynCom application enhanced plant growth under greenhouse or field conditions (Armanhi et al. 2021, Wang et al. 2021). Both *top-down* and *bottom-up* strategies to construct SynComs may provide complementary information and results, including predictable phenotypes, despite limitations persist in both models (Toju et al. 2018; Shayanthan et al. 2022). Promising technologies emerge, like the microfluidic droplet-based platform (kChip) (Kehe et al. 2019) that may automatically construct SynComs with all possible microbe combinations using a set of species. *Pseudomonas, Bacillus, Enterobacter, Acinetobacter,* or *Pantoea* are examples of PGP bacteria (Bonatelli et al. 2021), while *Trichoderma*, *Fusarium*, and *Penicillium* represent examples of PGP fungi. Currently-marketed products of PGPs often face unpredictable efficacy, raising questions about environmental safety. Again, advances to the current state of the art require improved efficiency and stability in formulation and delivery.

1.1.2. DESCRIPTION OF THE CHALLENGE (MAIN AIM)

Challenge 1) Europe faces old and new challenges to Sustainable food supply: Conventional agricultural systems aiming at ensuring food security, heavily depend on: **a)** commercial fertilizers and/or pesticides that (a.1) contaminate environments; (a.2) pose health risks to consumers; (a.3) potentiate the acquisition and spread of pathogens' resistance against antimicrobial compounds; (a.4) have costs to producers; (a.5) fragilize (pan)European market that relies upon the importation of raw material for fertilizers and pesticide production; **b)** high energy costs and fertirrigation inputs: Energy is a critical resource for agriculture, and this need is aggravated by geopolitical instability and climate change risks. Therefore, limitations in Water and Energy resources strongly impact agriculture and the commodity/product's final price to consumers; **c)** monoculture practices promote genetic erosion: undervaluing the local biodiversity and leading to genetic erosion of used cultivars and their associated microbiomes, resulting in the increase of plant diseases and some pathogen populations; **d)** plant's genetic potential: its research has been focused on improved cultivars/hybrids (selected mostly for high productivity). The selection of a single specialized crop trait was detrimental to the concept of holobiome, and the benefits of the plant´s microbiome. It is acknowledged that European agricultural systems are more vulnerable and less sustainable due to an overreliance on agrochemicals, and the increase of both resistance and resurgence of pests and diseases (Silva et al. 2019, foodwatch.org). Additionally, the most widely grown cultivars are not adapted to the challenges that we face today, namely the energetic crisis, the instability in the fertilizers market, and the urgent need to manage water better. On the other hand, Europe and many regions face an increase in the frequency of drought and heat waves and the appearance of new diseases. Technological solutions ensuring 3S-agriculture must align with the unifying policies of the Green Deal (//ec.europa.eu/), the UN-SDGs (e.g., 2, 12, 13, and 15 (//sdgs.un.org/goals), and the WHO One Health (www.who.int/). In the EU, the "Biodiversity Strategy" strengthens the interdependence between biodiversity and agriculture, and the "Farm to Fork" aims to reach by 2030 a ~50% reduction of toxic agrochemicals, and 25% of the EU's agricultural land to be cultivated organically. Intensive agriculture systems also rely on improved cultivars/hybrids, which were selected to increase productivity under abundant irrigation, not being adapted to prolonged drought/heat waves. For the EU+UK, it is estimated that the losses from drought will reach ~9 thousand Million €/yr, of which 39-60% will be due to agricultural losses (Cammalleri et al. 2020). Also, the selected commercial cultivars/hybrids are more susceptible to invasive pests/diseases. Climate change acts, together with trade (which is responsible for half of the emerging plant diseases and several plant-parasite populations with high impact in Europe), to potentiate new diseases, which often are impossible to eradicate. Their impact on production translates into economic and social consequences, affecting (pan)European food security in multiple dimensions: access, availability, utilization, and stability, and being smallholders particularly susceptible.

Challenge 2) How can Plant Microbiomes contribute to precision 3S-Agriculture? The Action aims at gathering (pan)European experts to coordinate and develop new knowledge on plant-microbiomes networking for application in precision 3S-Agriculture. The Action also aims to explore technological advances (e.g., engineered microbiomes) to selectively improve the fitness of holobionts, addressing challenges associated with new cropping systems, climate change, and diseases. The following challenges will be addressed by Exploiting Microbiomes in Precision Agriculture using an All-in-One Vision toward a Security-Safety-Sustainability in Agriculture (3S-Agriculture). The networking also aims at applying a holobiome improvement strategy to decrease the current losses of crop production due to pests, accounting for annual losses of up to 40% of the global crop production (~290 thousand Million USD). Invasive pests and pathogens are also the main drivers of biodiversity loss (https://www.fao.org/), aggravated by the overuse of broad-spectrum pesticides. An objective of CropBiomes is also to capitalize on (and share) the knowledge of the benefits of hub-associations in the crops' microbiomes (e.g., PGPs and MBCAs) toward replacing agrochemicals, contributing to reducing the 40% of losses during production, which will also represent corresponding savings in energy and water use. Thus, the Action will contribute to a 3S-Agriculture, by considering the holobiomes (integrating rhizosphere, phyllosphere, and endosphere) role in the crop's performance. Also, the dynamics of stable vs. transient microbial populations in response to abiotic and biotic stressors remain little explored. Nevertheless, this knowledge is pivotal to understanding the best microbiome assembly and homeostasis that potentiate both crop yield and resistance to challenges. This COST Action aims to explore a comprehensive knowledge of the phyllosphere and rhizosphere assembly/networking, dynamics underneath, conditions leading to dysbiosis, and their impact on plant defenses. Assembly of this knowledge is still in its infancy, being scattered and uncoordinated among different research groups. Improving the knowledge on the impact of individual drivers on the interactions between microbial-microbial populations, and microbiota-plant will allow manipulating the microbiome (SynComs) towards promoting targeted microbial species beneficial for the desired traits.

1.2. PROGRESS BEYOND THE STATE-OF-THE-ART

1.2.1. APPROACH TO THE CHALLENGE AND PROGRESS BEYOND THE STATE OF THE ART

The CropBiomes concept is grounded on the urgent transition to Sustainable Agriculture ensuring food Security and Safety (3S-Agriculture), aligned with the EU GreenDeal, and both “Farm to Fork” (F2F) and “Biodiversity” Strategies. With this concept, the crop is considered a holobiont responsible for its fitness, but the responses to abiotic or biotic challenges are yet underexplored in agriculture. It also opens a new field to engineer the microbiome (e.g., exploring “hub” taxa), towards potentiating community-scale networks in the holobiome (Toju 2018b), and its fitness in specific environments.

The CropBiomes Action will coordinate inter/transdisciplinary Working Groups (WG) that will discuss, generate and exchange knowledge on novel topics related to the plant microbiomes, bringing this field and synthetic communities to the next level in precision 3S-Agriculture. This breakthrough concept is only possible now with the multiOmics data accessibility (e.g., fast and easy metagenomic analysis), and metadata analysis that provides possible combinations of PGPs and MBCAs, studying compatibilities and antagonisms. Taking breakthrough knowledge to address 3S-agriculture aims, will be achieved by an interactive exchange of data, identifying knowledge gaps, defining and discussing hypotheses and models, proposing recommendations for future research directions, and promoting innovation. The CropBiomes Action will position this network as a leader in this field, providing innovative solutions for precision 3S-agriculture (e.g., deep-tech), and maximizing its yields. CropBiomes is thus timely at the global and European levels, having high market value. In addition, as crop holobiomes are a new transdisciplinary field with huge applied potential, CropBiomes will contribute to its implementation in Europe, including training a new generation of young researchers in this field.

1.2.2. OBJECTIVES

1.2.2.1. Research Coordination Objectives

CropBiomes aims at coordinating in an open and bottom-up way, the available knowledge on plant´s microbiome assembly, and its potential to increase crop holobiome resistance to drought and heat, or diseases. To achieve this aim, technologies targeting the plant-microbiome cross-talk mechanisms, and the holobiome (epi)genetic regulation under different cropping and environments will be analysed. The Action will also explore recent advances in engineering microbiomes, and aid in developing management and policy tools to improve the resilience of crop plants. To achieve this aim, CropBiomes sets a scientific networking platform that will, in coordinated Working Groups, discuss and analyse the current knowledge, and research aspects of plant microbiomes, and technological developments for 3S-agriculture. Research groups and stakeholders will discuss the exploitation of the microbiome to improve production and adjust the holobiome fitness to each specific environment. The gathered information will be used to manipulate the plant microbiome toward mitigating climate change and diseases. Specific research objectives (O1-O6) were aligned with the work plan, to:

O1. Develop understanding at the molecular level of assemblies and signaling regulating phytobionts. The Action aims to go beyond the current state of the art, including conceptual advances on microbiome-plant signaling pathways, candidate hub-species, microbiome regulatory functions of the crop fitness, the role of the microbiome on (epi)genetic regulation, even after inoculum removal (“memory”), etc. The Action aims to coordinate knowledge on processes of data acquisition and assessment.

O2. Develop understanding (theoretical vs experimental achievements), regarding “keystone microorganisms” to improve microbiome assemblies under different cropping systems. For example, characterizing microbiome assemblies and networks in different models (e.g., wild vs. domesticated cultivars), crop-ecosystems (rhizosphere, phyllosphere, endosphere), cropping conditions (e.g., comparing soil versus hydroponic/aeroponic cultures, exploiting the use of microbiomes in highly controlled systems like the vertical-production), different (a)biotic stresses and the roles of stable versus transient microbiomes. The Action also aims to coordinate knowledge on the availability of collections/curation of strains among the partners and other interested institutions, etc.

O3. Develop understanding (theoretical vs experimental achievements) on the interference of abiotic stress (heat and drought) and biotic stress (e.g., pathogens) on microbiome associations,

and exploit how keystone microorganisms (e.g PGPs and BCAs) improve crop performance/tolerance: Capitalize local genetic resources (e.g., varieties) as sources of local PGPs, improving crops to respond to drought or heat. PGPs, or MBCAs, with potential for (i) directly targeting pathogens or parasites; (ii) acting as plant defense elicitors.

O4. Engineering communities for successfully improving holobiont fitness. Evaluate the best conditions for compatible strain combinations and their sustainable application in the host. The Action will apply transdisciplinary knowledge and "deep-tech" to exploit new models of microbiome engineering to improve crop fitness according to the specific environment.

O5. Develop databases on plant microbiomes, and tools to make them (as much as possible) of wide Open Access. Besides these databases, 'the Action also aims at promoting agreement in concepts, and accessibility of research infrastructures and know-how among the participating countries, widening to other countries and users. A platform for database access will include dedicated sites/webpage.

O6. Provide inputs to stakeholders for solutions for a precision 3S-Agriculture. The Action aims to increase public awareness of the current drivers in agriculture, and the challenges in transitioning to an agroecology-based precision system. The Action will involve a) dissemination for the scientific community, stakeholders, and the general public for the perception of the potential of crop holobiomes; and b) the evaluation of the technological concepts/solutions/pilots (including evaluating the reached Technology Readiness Levels- TRLs), and economic impacts to industry and society. The Action will involve agroindustry and other stakeholders to intensify connections between academics, research and socio-economic actors.

1.2.2.2. Capacity-building Objectives

The Action aims to establish a (pan)European network of excellence among research groups, the private sector, regulatory authorities, and the consumers and public, increasing Europe's competitiveness, by:

O7. Stimulating long-lasting transdisciplinary research network on plant microbiomes, with a joint R&D&I agenda. This network will work interactively and invite other groups/countries to also integrate the network. This network agenda will be unique and allow bridging different research expertise (e.g., multi-omics, molecular and cell biology, (micro)biology, agriculture, horticulture, biotechnology, biochemistry, statistics, genetic engineering, spectral analysis, bioinformatics, metadata analysis), to respond to the Societal challenge of 3S-Agriculture.

O8. Involve long-term interactive balanced networks. The Action aims to contribute to equal access and participation in the construction of critical mass in different regions, providing opportunities to underrepresented groups/gender, nationalities, and age, fostering balanced participation of all actors. Special attention will be devoted to Young Researchers and Innovators, aiming to contributing to their development and their career opportunities.

2. NETWORKING EXCELLENCE

2.1. ADDED VALUE OF NETWORKING IN S&T EXCELLENCE

2.1.1. ADDED VALUE IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

The UN promotion of OneHealth and SDGs, articulated with the GreenDeal and both "F2F" and "Biodiversity" Strategies, represent pivotal compromises, gathering researchers-society-stakeholders and decision-makers in joint efforts for a sustainable world. CropBiomes Action is aligned with the Horizon Europe Cluster 6 (Food, Bioeconomy, Natural Resources, Agriculture & Environment), to reduce environmental degradation, promote biodiversity, and better manage natural resources while ensuring food and water security (e.g., the Cluster 6-F2F Programme "Microbiomes in food production systems" was open to plant/animal/human microbiome/microbiota).
Previous Grants on the H2020 dealing with microbiomes in food production, are increasing but remain few, and often covering animal/fish and plant production as are the cases of "Master", "Circles" and "Simba" grants. Other grants focusing on plants target almost only the rhizosphere under different conditions. We identify some grants of *H2020-EU.1.3.* like "Rootphenobiome", "Apple-Biome",

"RhizoMIR", "MetaFun", "MetalSym", "Direction" (on resistance to *Fusarium*), "PinBac" (on nutrition), and "3D-Plant2Cells" (pesticide impacts), "Sense", or "BestPass" (addressing endophytes). The *H2020-EU-3.2* funded e.g., "XF-Actors" (addressing *Xyllela*); "Romance", "MetalSYM" (addressing mycorrhizal fungi), or the VIROPLANT (addresses virus-plant interactions), "SolACE" (addressing soil/water efficiency), "Excalibur" (exploiting soil biodiversity), "Musa" (focused on *Musa sp.*). In other Programs, like ERCs, we highlight the "Sym-Biotics" (addressing *Rhizobium*), "Decipher" (multiple animal/plant models), "PhyMo" (phyllosphere microbiota), or "MicroRules". Also, a few PRIMA Networks addressed microbiomes on improving Mediterranean agroecosystems (e.g., "Vineprotect").

It is evident that an enormous effort is ongoing in the research of plant microbiomes in Europe, and it is time to integrate a network to promote, organise and exchange this generated knowledge, which is still sparse. A search for active or closed COST Actions shows that those dealing with crop production and sustainable agriculture did not focus on plant microbiomes or Synthetic Communities. The "CA16110" Action addressed Human pathogens in plant-production systems, while the "FA1206" Action addressed strigolactones, "FP1305" covered belowground microbiota of forests, and the "631" Action addressed rhizosphere interactions, but no COST action addresses the crop as a holobiont.

This search clearly shows that CropBiomes responds to a gap in knowledge coordination in fields of plant-microbiome interaction, engineering, and crop holobionts. CropBiomes responds to the need to (*i*) coordinate, promote, and exchange the generated data from those and other inter/national projects, publications, etc; (*ii*) foster interdisciplinary breakthroughs in the field of crop microbiomes, and (*iii*) promote young researchers' capacities. CropBiomes is the first network fully dedicated to apply these priorities to the field of Plant Microbiomes (from deep research to agriculture). This Action will pioneer (pan)European Competitiveness in RD&T in this field by (*i*) exploiting research fields yet underexploited in research or grants, like the SynCOms that represent a breakthrough for precision agriculture, (*ii*) contributing to sustainable precision agriculture aligned with the F2F and Biodiversity strategies, (*iii*) build long-term networks gathering transdisciplinary experts, being the basis for further initiatives; (*iv*) capitalize knowledge on local microbiomes, and biodiversity, which remains underexplored in scientific networks.

The capitalization of the knowledge generated in previous and ongoing (inter)national projects (inside and outside the network) will also support long-lasting collaborations.

2.2. ADDED VALUE OF NETWORKING IN IMPACT

2.2.1. SECURING THE CRITICAL MASS, EXPERTISE AND GEOGRAPHICAL BALANCE WITHIN THE COST MEMBERS AND BEYOND

Contribution to a Geographical Network of Critical Mass and Excellence: The Action participants will gather several leading researchers in plant microbiomes and associated fields. Moreover, when addressing crops, researchers have focused mostly on rhizobiomes, remaining the phyllosphere microbiomes understudied. Thus, this Action will create new collaborative research regarding geographical balance, interdisciplinary dialogues, exchange of experiences between experienced and young researchers, and between researchers/innovators from different sectors, exchanging knowledge with stakeholders and society. This Action will set up (i) a coordinated study of the crop holobiome, and its dynamics under different environments (plant organs/ecosystems, cropping models including soils and hydro/aeroponics, drought/heat stress, pathogen/parasite infection, disease suppressive/conducive soils, etc; (ii) integration of available/new solutions for the precision 3S-Agriculture. Being a highly complex transdisciplinary field, with the diversity of agro-ecosystem contexts and processes across (pan)Europe, it is important to address the assembly of microbiomes from the molecular perspective to the macro-agronomical applications under a climate change scenario. This requires gathering experts from different fields (molecular cell biology, bioinformatics, agronomy, horticulture, microbiology, biochemistry, biotechnology, plant physiology, multi-omics, statistics, etc). In summary, by studying the crop as a dynamic assembly of multiple taxa (crop holobiont), this Action will consolidate, structure knowledge, and jointly coordinate solutions (taking into consideration region-specific conditions in their implementation and impacts.

Fostering interdisciplinary and intersectoral innovations for solutions for a 3S-Agriculture: CropBiomes covers this RD&T gap, representing a unique contribution to consolidate international collaborations and European competitiveness. This Action will include participants from different countries and will expand during its implementation, aiming at reaching the highest quality in all aims and endeavours. The network will have an inclusive representation of most critical fields like phytopathologists at the forefront of BCAs and PGPs; experts in phytobiomes; microbiologists; biotechnologists; agronomists and horticulturists of several crops; plant molecular and cellular biologists; geneticists; plant health and crop protection specialists; soil experts, bioinformaticians, environment experts, etc. It will also combine academics, producing associations, and industry. This network focuses on progressing the state of the art and development of breakthroughs. It aims at finding solutions that cover representative producing systems and agricultural contexts.

The network will involve different participants generating a “roadmap” in “plant microbiomes and Synthetic Communities” relevant to agriculture. With the proposed activities, CropBiomes will attract young researchers from participating countries and other countries, strongly consolidating this topic in more research groups, universities, and companies.

2.2.2. INVOLVEMENT OF STAKEHOLDERS

Aligned with the knowledge transfer activities, the Dissemination/Communication Plan (Section 3.2.2), will also include plans for Stakeholders’ Engagement, with guidelines considering the activities and expected results, and covering different and relevant audiences and stakeholders, ensuring their involvement in the activities. The Action will also ensure a balanced involvement regarding both the gender and geographical origin of the stakeholders. The diversity of the stakeholder groups: Scientific/Academic community. CropBiomes will target researchers of multiple research basic and applied fields, to exchange knowledge and translate results to the field. It will impact a vast scientific community, bringing researchers together to discuss new knowledge and technologies. Students, Young Researchers and Innovators (YRI)/Professionals. The Action will include a high number of students, YRIs, and other professionals with interests in the field. They will be stimulated to actively participate in capacity activities, management structures, and dissemination/communication. Whether members or not of CropBiomes, YRIs (students, postdocs, or other young professionals) may apply and attend training schools, Short-Term Scientific Missions, and other events. They will consolidate transdisciplinary and soft skills, benefiting their career development, strengthening and widening their networking, and potentiating opportunities for their recruitment. Agri-food Industry/SMEs/Associations/Cooperatives. The results emerging from this COST Action will be of high importance to e.g., biotechnology/microbiology/agriculture industrial stakeholders. Thus, the Action will be strongly engaged in contacting them and promoting actively lasting collaborations with industry, including through recurrent invitations to a wide portfolio of industries, to participate in the COST activities and to notice that some of these industry stakeholders can benefit from more advanced knowledge for developing and commercializing new biocontrol products.

General Public/Civil Society. Reaching the general public is pivotal, as it also includes consumers, students at schools, etc., and all together, create social trends and influence policies. Their engagement through e.g., social media, online/face-to-face events, and the Press, will be promoted to divulge CropBiomes. The Action will actively work on informing the public about the challenges, current knowledge, and solutions of this Action. This will be pivotal to creating awareness of the importance of this field.

Policymakers/Funders/International Agencies in the agricultural sector. Policymakers and other stakeholders must be periodically informed of this Action results. So, they will be invited to meetings, and contacted with dissemination/communication activities. This is pivotal to engage these groups and feed relevant policies (inter)national levels. Also, the Action will actively interact with International Agencies (inviting them to network events) to disseminate new knowledge for agricultural applications.

3. IMPACT

3.1. IMPACT TO SCIENCE, SOCIETY AND COMPETITIVENESS, AND POTENTIAL FOR INNOVATION/BREAK-THROUGHS

3.1.1. SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS (INCLUDING POTENTIAL INNOVATIONS AND/OR BREAKTHROUGHS)

CropBiomes integrates an interdisciplinary-intersectoral community to strengthen communication between researchers-stakeholders-society, for crop-microbiomes applications to precision 3S-agriculture. The impact will follow the COST Mission & Strategies. Through its international framework, the Action´s outputs will be in the frontier of knowledge of phytobiomes, generate applied technologies (e.g., SynComs) for use in precision 3S-agriculture.

The Short Term (ST) impacts will also last and contribute to long-term impacts (below). The main ST impacts are: - Strengthen the (pan)European collaborations for breakthrough knowledge creation (e.g., deepen the concepts on holobiomes in agriculture) and exchange on the plant microbiomes in basic and applied dimensions, and apply that knowledge to the transition to the precision sustainable agriculture following F2F strategy. This will therefore reinforce the European research capacity in the field: i) Developed technologies for characterizing microbiome structures and engineering synthetic communities to be applied in precision agriculture; ii) Strengthen infrastructure and resources among the European research community to better management of resources in the multiple fields related to plant microbiomes and their use in agriculture; iii) Strengthen training (on different disciplines) of a new generation of researchers through new courses, and training schools related to plant microbiome studies; iv) Enhance the interest of (pan)European stakeholders, including industry in the technology and knowledge transfer using microbiomes in new biocontrol strategies/products for precision agriculture.

Important Long Term (LT) impacts, lasting much beyond the end of the Action, include new social perceptions for healthier food, new niches of the market for agricultural/biotechnology companies, and new job opportunities. Together LT impacts will include impacts-oriented to precision 3S-agriculture (capitalizing through the precision manipulation of plant microbiomes): i) Impact on Scientific Community Building: new RD&T will be generated, including the technology development (e.g., deep-tech). Creativity and bottom-up approaches will contribute to breakthroughs in precision agriculture. Also, this Action will create and/or strengthen new collaborative links in Europe promoting access of researchers to diverse models, tools & approaches; ii) Impact on Scientific Careers: Training and creating a new generation of YRIs and professionals dealing with the phytobiomes in precision agriculture and aware of the integrated vision of the 3S-agriculture, also aligned with the consumers' perception of healthier food, and sustainable origin; iii) Impact to strengthen a long-lasting transdisciplinary and Intersectoral Networking for the transition to precise agriculture, while also preserving biodiversity, and engaging new industrial partners from the biotechnology/agricultural sectors for this new research area, including the creation of commercial niches within Biotech Companies; iv) Socioeconomic and Environmental Impact: This Action will have socioeconomic impacts, besides training a new generation of YRIs, also the solutions proposed will impact producers to reduce the amount of food loss during production due to pests, save in agrochemicals, save energy, better use water, and capitalize local biodiversity/microbiomes and local varieties. There will also be an opportunity for scientists, farmers, and industry to discuss experiences and collaborate; vi) Increased Social and Consumer perception: Consumers will be attracted to this more sustainable production strategy, reducing the accumulation of agrochemicals in the edible vegetables and their residues contaminating environmental soils/water. Importantly, exploiting local biodiversity will also decrease European dependence on imported agrochemicals. The impact of this Action will be maximized through interactions with school teachers, technicians, farmers, etc.

3.2. MEASURES TO MAXIMISE IMPACT

3.2.1. KNOWLEDGE CREATION, TRANSFER OF KNOWLEDGE AND CAREER DEVELOPMENT

CropBiomes is aligned with the GreenDeal, and the Horizon Research Cluster 6, strengthening cross-border collaboration, critical mass, and European competitiveness in the RD&T of this breakthrough field of controlling the microbiomes of crops. This Action will facilitate exchange between academia and industry, and support technological development, namely deep-tech. It will also generate open-access knowledge for public decision-makers to design effective strategies.

All activities will be inclusive, in terms of gender, career stage, scientific background, and geographic origin (representing an opportunity for YRIs from less research-intensive countries).

Knowledge creation & Research Excellence across/beyond Europe: CropBiomes will coordinate new knowledge creation (holobiomes, and microbiome manipulation/engineering) both at fundamental and applied levels. To maximize the coordination of the generated knowledge, this Action will allocate specific topics to specialist Working Groups (see implementation), who besides bridging transdisciplinary and intersectoral knowledge, will interactively work with stakeholders.

Transfer of Knowledge and Intellectual Property Rights (IPR): CropBiomes pays particular attention to knowledge transfer, due to the high potential of the field in the agri-food sector, and thus a strong interplay between academy and industry is mandatory to ensure that generated knowledge is converted in (deep)tech/technology (e.g., replace agrochemicals). This will be performed using activities of the dissemination/communication plan (e.g., webpages, webinars, training schools, STSMs) in each Working Group. During the COST Action, activities of dissemination/communication in native languages will be created to make information available to different audiences.

This COST Action will also be highly focused on discussing strategies for Intellectual Property Rights (IPR), supporting business-plan elaborations, and commercialization rights. These pivotal aspects (including guidelines of intellectual property and ethical conduct) will be agreed upon by the participants at the beginning of the Action. This will count on the support of Partners' Legal Offices (e.g., Universities and companies) and consider the "Rules and principles for COST Activities".

Training YRIs and Career Development: This COST Action will open opportunities to establish networks of academic training/supervision through the organization of scientific/training activities (e.g., specialized training schools, seminars) to prepare the YRIs (e.g., students, postdocs, PhD-researchers). It will also promote the scientific community and YRIs training by mobility and connecting with other initiatives (e.g., Erasmus), joint Co-supervised Ph.D. (e.g., using existing Ph.D. Programs of participants), and the advantage of participants also applying for international R&D grants. CropBiomes will create a new generation of professionals that will take SynComs to a marketable level of sustainable biocontrol. Career development of YRIs is also pivotal for this Action. The network will join efforts to maximize the early potential and employment opportunities (short/long-term) for the YRIs, aligned with the European Charter for Researchers. For example, the Action will offer career development for young academics and give them perspectives for grants/funding beyond the lifetime of the Action.

Training will benefit from the cooperation of interdisciplinary teamwork and participating institutions. Aligned with the activities and Working Groups, this Action aims to provide training with the current knowledge generated in its activities. YRIs will also contact the private sector, and activities will be open to researchers from companies (e.g., from the biocontrol and bio-stimulant sectors).

CropBiomes will also be an opportunity for transferable skills. For example, YRIs will be stimulated to support leading activities in each WG, and their inputs incorporated into the activities.

3.2.2. PLAN FOR DISSEMINATION AND/OR EXPLOITATION AND DIALOGUE WITH THE GENERAL PUBLIC OR POLICY

The international visibility of this COST Action (and its focus of work) will require a Dissemination/Communication Plan (DCP). The DCP will disseminate research excellence on plant microbiomes, strengthen strategic cooperation agreements with universities, research institutions, and companies, and interactively disseminate/communicate the results through multiple vehicles. The DCP's main strategies for this Action (see Implementation) are:

Logo, Website, and Social Networks- At the beginning of the Action, a logotype and website dedicated to the CropBiomes will be set up, containing a brief description, mission, objectives, news, and events, which will be constantly updated. Simultaneously interactive links on social media (LinkedIn, Twitter, Facebook) will be created and engaging language (whenever necessary, translating to national languages).

Research Community Dissemination- CropBiomes will invest on disseminating results to the scientific community through Q1 journals, proposing special editions to journals (several members integrate editorial offices of several scientific journals), and participating in (inter)national conferences. Participants will adopt the European Open Access policy promoting open-access publications and ensuring the repository accessibility of data, following the necessary conditions of IPRs. The network will also provide breakthrough reports, review articles (in collaboration) to contribute to the dissemination of the topic and the new results.

Organizing Conferences/Workshops- The Action aims at organizing at least one conference per Working Group (WG) per year in a mixed regime (benefiting from Colibri or other online platforms to reach a vast audiences and promote a sustainable policy of reducing travels to the essential). When using the mixed format, meetings will be simultaneously transmitted in different countries and reach more people. The Action will support other events in the participants' academies, national societies, etc.), to widen participation, and promote critical discussion, and outputs of the WGs topics (e.g. local genetic resources, case studies). In the meetings, specific thematic researchers, members of regulatory authorities, or other stakeholders (e.g., industry) will be invited and openly discuss the approaches and advances. Abstracts/ communications will be subjected to scientific evaluation; those accepted will be published in abstracts/proceedings books, and some selected may be published as articles in journal special issues Dissemination to a Broader Public and Different Audiences. The Action will target different audiences at the broader public (e.g., from children to adults), using (i) interactive social media (see above); (ii) short videos, and webinars (10-20 min); (iii) flyers/brochures disseminated at public events in national languages, (iv) TV/Radio interviews in national languages; (v) participation in science fairs/days, and other outreach activities particularly dedicated to younger/family audiences; (vi) high-school visits and conferences for high-school students and teachers; (vii) a glossary of the topics terminology will also be published in the website, to help the public and students to understand the results.

Dissemination and Training Schools- The experts/members of CropBiomes will organize Training Schools to share theoretical and practical knowledge. For these Training Schools, experts outside the Action will also be invited for lectures/training. These Training Schools will be mostly dedicated to YRIs, but open to all researchers in related fields inside/outside the network, interested in the topic. External experts will participate by giving e.g., lectures. Attendance at these Training Schools will consider a balance of the COST ITC members as well as of YRIs' level of profile, and gender.

Short-Term Scientific Missions (STSM) and attendance of Conferences- The Action will create conditions to offer grants to YRIs for STSM promoting mobility and knowledge transfer between groups, and the attendance of conferences. For that, the candidates' applications will be evaluated (on a basis of transparency and inclusiveness). Evaluation of the report after the STSM will also be applied. In the conferences, granted YRIs (e.g., students) will disseminate CropBiomes.

Engagement and dissemination of the CropBiomes through (inter)National Scientific Societies- The Action will establish contacts with national and international scientific societies, and disseminate the CropBiomes and its topic(s) among those societies. This will strengthen the Action's impact and knowledge sharing. Synergies in arranging meetings may also benefit from the results of this engagement with scientific societies.

Communication with Associations, Industry, and Policy Makers- Communication of the Action outcomes (and their potential) to Associations (e.g., farmers, markets), industry, and local/(inter)national policymakers will be developed in all WG activities. The Action will create pitch presentations in brief meetings with e.g., industrials and policymakers, discussing how research innovation can promote the development of valuable strategies toward a precision 3S-Agriculture. Members of key biotechnology and agricultural industry and administrative sectors (e.g. Counties) will be invited to the Action conferences (including round tables) discussing challenges, opportunities, and risks associated with the sector and the proposed CropBiomes solutions.

This communication with Industry and other Innovation Stakeholders is crucial to rapidly take the results to a higher level of applicability. The technological transfer implies evaluating the technology readiness level (TRL), and environmental impacts. It also implies that the network aligns with the Intellectual Property Rights (IPR) principles (section 3.2.1). To better manage IPR issues, the WG-Leaders will agree in the first meeting on an exploitation plan that will be adapted to the participating countries' reality and updated when necessary. New products, protocols, or services being developed may include, for example, relevant isolates (e.g., PGPs, MBCAs), ancient crop varieties with specifically associated microbiomes, bioinformatic tools, pipelines, methods of engineering microbiomes, targeted for resistance to drought, or control a specific disease, etc. A specific exploitation procedure must be adopted for each case including, whenever necessary, licensing and/or patenting, following the necessary procedures to protect IPRs.

4. IMPLEMENTATION

4.1. COHERENCE AND EFFECTIVENESS OF THE WORK PLAN

4.1.1. DESCRIPTION OF WORKING GROUPS, TASKS AND ACTIVITIES

CropBiomes Management will follow the COST Rules for COST Actions management, considering also the Management Committee (MC) responsible for coordination, implementation, and management of the Action, and also considering the Action Grant Agreements (e.g., funding). CropBiomes is structured into 4 technical and 1 transversal Working Groups (WG, Fig. 1), with tasks/activities designed to answer the objectives (section 1.2.2) and reach the associated milestones/deliverables.

WG1. Exploiting Plant-Microbiome molecular crosstalks: diversity, distribution and eco-evolutionary perspectives: The Action will coordinate available knowledge/datasets on microbiome assemblies (stable and transient populations), and decipher phytobiome functional and molecular signaling, with molecular /metagenomic techniques. Knowledge will be transmitted on training and dissemination.

Task1.1. Knowledge advances on plant-microbiome assemblies, and available collections. Includes revising available publications, reports and grants/projects (inside and outside Europe), existing networks on the CropBiomes, and researchers' laboratorial data. The Action will focus, e.g., on (i) metagenomic analysis (amplicon sequencing) of above- and belowground assemblies, considering multiple variables (cropping system, soil/hydroponics, varieties, water adsorbing materials (hydrogels), soil suppressiveness status, etc); (ii) ecto/endosphere assemblies; (iii) available collections of isolates/strains; (iv) guidelines and reference materials to omics research, and best procedures of isolation/culture.

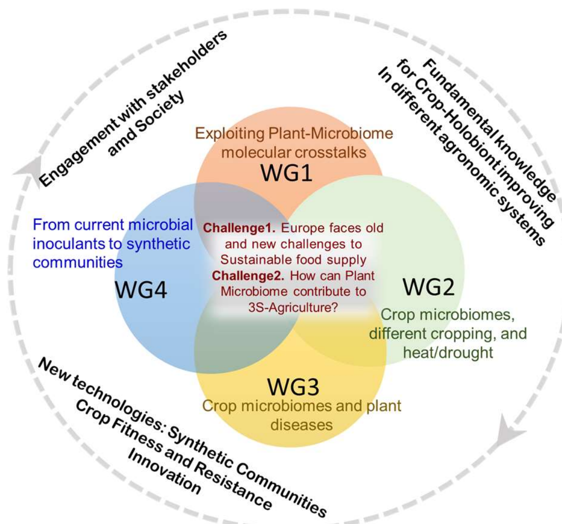

Fig.1 CropBiomes WGs to address the challenges and outputs

Task 1.2: Knowledge advances functional molecular models, and transcriptomics, mapping microbe-microbe, and microbe-plant interactions. Includes discussion of the advances (literature and the participants experimental advances) in the mapping of these genome-wide associations, The Action will particularly focus on the systematic characterization of the molecular basis regulating microbial-microbial interactions (particularly positive and negative), and of each population/community with the plant. The Action will recognize key plant genes involved in the (i) recognition of microorganisms constituting the microbiome, modulation of the microbiome's functional networks (microbe-microbe and microbe-plant), and identify knowledge gaps. Recommended approaches for unveiling network relations, hub-gene mapping, etc. will also be explored to find robust approaches for diagnosis of e.g., hub taxa, and microbe-host signals/receptors that might act as reporters. An important focus will be the study of recent models for epigenetic regulations of the "crop-holobiome" and generated "memory" phenotypes.

Task1.3. Knowledge advances on eco-evolutionary perspectives. The Action explore how microbiome eco-evolutionary dynamics determine host fitness, considering the microbial-microbial populational interactions (negative/neutral/positive) and the factors that condition microbial-host interactions (varieties, organs/tissues, cropping systems, edaphoclimatic conditions, etc). The genetic diversity of microbiomes and co-evolutionary relations in soilless systems will be explored. Additionally, the Action will explore the possibility of prediction from community associations, and key exploit molecular markers.

Task 1.4. Promote Training and Dissemination, including a Conclusion WG Report on major findings. Besides WG1 regular meetings, the Action aims at organizing per year at least 1 Congress/Workshop, and 1 Training School. Other activities include promoting STSMs, and supporting mobility to external events, etc. Advances in concepts, glossaries, and models will be released in papers and in a Conclusion WG Report.

Deliverables and Milestones: D1.1.- at least 2 technical collaborative Q1 papers in WG1 topics; D1.2.- Diverse Press news (webinar, journal/radio new, interview, posts, etc) on WG1 activities (compiled in Months 12,24,36,48); D1.3.- Conclusion WG Report; Milestones: Mil1.1-1st WG1 meeting; Mil1.2.- 1stConference/Workshop organized;

WG2. Crop-Microbiome assembly dynamics under specific environments: the Action willl coordinate the available knowledge/datasets on changes in microbiome dynamics (rhizo/phytobiomes), networking assembly, and relation to the crop growing under specific environments: a) drought and/or heat (associated with climate change); b) soil/soilless systems.

Task2.1. How do Microbiomes respond (assembly and function) to climate and other environmental changes? Includes revising available publications, reports and grants/projects (inside and outside the network), and our experimental/laboratory outputs. The Action will focus on: (i) how do global changes (namely drought and heat waves) and other environmental conditions affect the plant and microbiome (e.g., metagenomics and metatranscriptomics)? (ii) can these perturbations cause selective pressure on the microbiome assembly? (iii) as plant-associated microbiomes contain multiple taxa, how can these perturbations influence lateral gene transfer and the microbiome adaptation to global changes is a pivotal question? (iv) How do shifts in microbiomes influence plants' fitness under these challenging conditions? Gathering knowledge on host-microbiome interactions using metagenome-assembled genomes, and molecular, physiology, transcriptomic, metabolomic, and integrative biology will be exploited for the database construction.

Task 2.2. How can Phyllo/Rhizosphere cooperations increase crops' tolerance to drought and heat? Breakthroughs will include exploiting isolates/species promoting plant tolerance to climate change, and the mechanisms used, namely by modifying the physical environment (e.g., biofilms), secreting plant hormones (e.g., auxins, cytokinins), stimulating defense-related proteins, modifying plant gene expression; or by promoting plant access to nutrients (eg., N, P, K). The Action will explore molecular pathways of how keystone microorganisms (eg., PGPs) improve crops to resist drought and heat waves.

Task 2.3. How do crop microbiomes reshape under soilless agricultural systems? The Action will compare the effects of soilless systems on the microbiome's genetic structure composition, on predominant pathogenic populations, and their relationship with the microbiome. The Action willl also analyse candidate keystone microorganisms beneficial for crop growth in soilless greenhouse systems. It is important to discuss how matrices (eg, nanoformulations, hydrogels) and medium composition determine the effectiveness of PGPs amendment in these soilless systems. Also, how nutritional aspects (N, P, K, etc) influence and are influenced by microbiomes in soilless systems will be studied. Impacts on new closed/vertical systems will also be discussed, involving stakeholders.

Task 2.4. Promote Training and Dissemination, including a Conclusion WG Report on major findings. Besides WG2 regular meetings, the Action aims at organizing per year at least 1 Congress/Workshop, and 1 Training School. Other activities include promoting STSMs and supporting mobility to external congresses, etc. Advances in concepts, glossaries, and models will be released in papers and in a Conclusion WG Report.

Deliverables and Milestones: D2.1.- at least 2 technical collaborative Q1 papers in WG2 topics; D2.2.- Diverse Press news (webinar, journal/radio, interview, posts, etc) on WG2 (Months 12,24,36,48); D2.3.- Conclusion WG Report; Milestones: Mil2.1-1st WG2 meeting; Mil2.2.-1stConference/Workshop organized.

WG3. Crop microbiomes and plant diseases: from dysbiosis to increased defenses: The ecological processes that govern plant microbiome assembly and functions in both the below- and above-ground organs, and their disruption by pathogens, are not fully understood.

Task 3.1. How does Microbiome assembly shift in response to pathogens? Includes revising available publications, reports, grants/projects (inside and outside Europe), existing networks in phytobiomes, and our experimental outputs. Key questions to explore include, for example, (i) if pathogens cause dysbiosis, or if is dysbiosis facilitating pathogens to cause the disease. The Action will explore types of plant microbiome modulations, including transient microbiome shifts, stabilization or increase of plant microbial diversity, and the microbiome uniformity, evolution to dysbiosis, and dysbiosis-compensation. Also, molecular pathways toward understanding beneficial indigenous taxa/strains on suppressing potential pathogens will be explored. Finally, it is pivotal to coordinate the inputs on the impacts of current control strategies on the phytobiome and resistome.

Task 3.2. How can phyllo/rhizosphere cooperations be recruited for crops' defense? The Actionwill discuss the current state of the art on this topic, namely molecular aspects of the capacity of roots of pathogen-infected plants to attract beneficial microbes for rescue ("cry for help" strategy). This has been proposed also for the phyllosphere. Recruitment mechanisms remain obscure but may involve, e.g., volatile organic compounds or modifying synthesis, particular exudates, and signaling pathways (Cellini et al 2021). The mechanisms of beneficial microbes to the holobiome and disease suppression may involve mechanisms of priming the plant immune system, excreting antibiotic compounds, and competing for resources with the pathogen, models of action that will be further explored.

Task 3.3. Promote Training and Dissemination, including a Conclusion WG Report on major findings. Besides WG3 regular meetings, the Action aims at organizing per year at least 1 Congress/Workshop, and 1 Training School. Other activities include promoting STSMs and supporting mobility to external congresses, etc. Advances in concepts, glossaries, and models will be released in papers and in a Conclusion WG Report.

Deliverables and Milestones: D3.1.- at least 2 technical collaborative Q1 papers in WG3 topics; D3.2.- Diverse Press news (webinar, journal/radio new, interview, posts, etc) on WG2 activities (compiled in Months 12,24,36,48); D3.3.- Conclusion WG Report; Milestones: Mil3.1-1st WG3 meeting; Mil3.2.- 1stConference/Workshop organized.

WG4: From current microbial inoculants to synthetic communities: Here, it is argued in favour of using the SynCom concept to create consortia of keystone microbes to enhance plant production and resiliency against biotic and abiotic stresses in agriculture. Tasks and Activities

Task 4.1. Data collection, literature review on SynComs. Includes revising available publications, reports, grants/projects (inside and outside Europe), existing networks on this topic, and our laboratory outputs. The Action will compile information on the genome/metagenome sequences of microbiomes, along with microbial profiling, and analyse how these metadata could help the design of SynComs (top-down/bottom-up, etc) that confer stable plant phenotypes and promote robustness for stable and lasting plant colonization. The Action will explore relevant bottlenecks, functional gaps, and underexploited tools in the plant microbiome that may help to develop novel strategies for bridging microbial ecology and screening procedures associated with microbial functions towards developing microbiome technologies for agricultural sustainability.

Task 4.2 Variables influencing the stability and efficiency of synthetic communities. The Action will contribute to going beyond the current state of the art by exploiting, for example, factors conditioning a successful inoculation. This involves, for example, competition with indigenous microbes, organ-dependent efficiency, and the degree of stability of the associations. Limitations on current screening approaches for selected traits to elicit a desired phenotype in the host will also be studied.

Task 4.3. Construct stable and efficient SynComs: from lab to field. The Action will generate knowledge from the current state of the art on this subject. The Action will explore for example the impact of lowering the complexity of microbial assemblies. The Action also discuss concepts of SynComs in precision Agriculture, namely designing communities that incorporate the desired set of microbial traits for agriculture. The frameworks for tailoring stable and effective SynComs to enhance crop resistance/fitness will be discussed. Strategies using top-down/bottom-up approaches, and "microchips" will be explored.

Task 4.4. Promote Training and Dissemination, including a Conclusion WG Report on major findings. Besides WG4 regular meetings, the Action aims at organizing per year at least 1 Congress/Workshop, and 1 Training School. Other activities include promoting STSMs and supporting mobility to external congresses, etc. Advances in concepts, glossaries, and models will be released in papers and in a final Conclusion WG Report.

Deliverables and Milestones: D4.1.- at least 2 technical collaborative Q1 papers in WG4 topics; D4.2.- Diverse Press news (webinar, journal/radio, interview, posts, etc) on WG4 (Months 12,24,36,48); D4.3.-

Conclusion WG Report on variables influencing associations; Milestones: Mil4.1-1st WG4 meeting; Mil4.2.-1stConference/Workshop organized.

WG5. Communication, and engagement with society: This WG gathers mostly the engagement with society and coordination activities.

Task5.1 Engagement with stakeholders: coordinates the proper engagement with stakeholders.

Task5.2. Coordination of dissemination activities (see 3.2.2), namely the website and social media platforms for networking activities. For example, (i) Training Schools (>1/year/WG). Also, >1/year workshop/conference will take place per WG (1-4); (ii) Short-Term Scientific Missions. STSMs will be organized in each WG. Also, mobility for attending events/congresses organized by other entities is provided. Webinars will be organized by YRIs and other partners, on the thematic issues. This Action will also be deeply engaged with other co-tutoring programs like ERASMUS programs, Master and Ph.D. Programs, postdocs, adding value to the background of the next generation of scientists and improving their employability.

Deliverables and Milestones: D5.1.- website creation (M3); D5.2.- Agreed Dissemination and Communication Plan (confidential) (M3); D5.3.- Press newsletters on the COST activities (Months 12,24,36,48)

4.1.2. DESCRIPTION OF DELIVERABLES AND TIMEFRAME

Table3.1 List of Deliverables. Except when referred all will be Public by the end of the Action

#	WG	Description	Month	Type
D1.1	1	Technical collaborative papers in WG1 subtopics - This WG will produce/publish international papers on the topics of the Group	42	rep
D1.2	1	Press news on WG1 activities - several news, webinars, will be published on social and other conventional media on the work developed by the WG1	12, 36	media
D1.3	1	Conclusion WG1 Report on the main achievements regarding the Plant-Microbiome molecular crosstalk (e.g., distribution and eco-evolutionary perspectives)	48	rep
D2.1	2	Technical collaborative papers in WG2 subtopics - This WG will produce/publish international papers on the topics of the Group	42	rep
D2.2	2	Press news on WG2 activities	12, 36	media
D2.3	2	Conclusion WG2 Report on the main achievements regarding the Crop-Microbiome assembly dynamics under specific environments	48	rep
D3.1	3	Technical collaborative papers in WG3 subtopics - This WG will produce/publish international papers on the topics of the Group	45	rep
D3.2	3	Press news on WG3 activities - several news, webinars, will be published on social and other conventional media on the work developed by the WG3	15,45	media
D3.3	3	Conclusion WG3 Report on knowledge-based information regarding the Crop microbiomes and plant diseases	48	rep
D4.1	4	Technical collaborative papers in WG4 subtopics - This WG will produce/publish international papers on the topics of the Group	36,46	rep
D4.2	4	Press news on WG4 activities - several news, webinars, will be published on social and other conventional media on the work developed by the WG4	18,45	media
D4.3	4	Conclusion WG4 Report on the knowledge-based information regarding establishing and potential of synthetic communities	48	rep
D5.1	5	Website creation: the Action network will create and update during the action duration a website with main achievements	3	media
D5.2	5	The Action Network will release Press newsletters on the COST activities and the main achievements, periodically highlighting key networks, joint collaborations, and main achievements	12,24,36,48	media

4.1.3. RISK ANALYSIS AND CONTINGENCY PLANS

WG Leaders will update the WG's SWOT analyses, risks, and mitigation measures. These analyses help monitor the weaknesses/threats of each WG, and an accurate and appropriate risk monitoring/ management. Some risks are listed in Table below.

Table 3.3. Risk description, Likelihood (*1-Low; 2-Medium; 3-High*), and Severity *(VL-Very low; L-Low; M-Medium; H-High)*, and proposed mitigation measures

Risk description, likelihood (1-3), and severity (Low /Medium/ High)	WG	Mitigation measures
A leader is incapable of doing duties (e.g. illness) (1; VL).	1-5	Another participants helps or replaces the leadership of that leader (temporary or definitive)
Low efficiency in management, disputes, or lack of involvement of a participant (1;L/M)	1-5	Administrative issues/aspects will be discussed in the first meeting. Also, guidelines and videoconferences can be arranged to clarify deficient issues. Whenever necessary, Leaders will look for a compromise.
A participant has difficulty to perform an allocated task (1:L/M)	1-5	Planned work will be distributed to other participant(s) with adequate expertise

Poor quality or delay of deliverables *(2;L/M)*	1-5	Meetings to improve rules/guidelines for handling deliverables in due time
Delay in meeting the deadlines *(2:L/M).*	1-5	Deadlines for submission of deliverables is set in advance. Leaders ensure that WG participants adhere to the deadlines (milestones and deliverables). Meetings will take place for handling in due time the necessary deliverables. The need for help of other participants may be discussed.
Unpredicted risks like geo-political instability, or pandemics limiting travels *(2:M/H)*	1-5	Despite research schools, conferences/workshops are planned to be face-to-face, if necessary, online alternatives will be adopted. Participants have experience in organizing online events
Budget constraints *(1:L/M)*	1-5	The rigour of financial management will be ensured. In case of insufficient budget, alternative measures will be considered (e.g., increasing online participation). Participants can complement the budget with additional National and European sources.
Limited involvement of other stakeholders (e.g., insufficient participation at events) *(2:L/M)*	1-5	Some non-academic members will integrate this network. Each participant will also have its own network of stakeholders. High engagement with stakeholders will be put from the beginning (eg DCP).

4.1.4. GANTT DIAGRAM

Table 3.4. Gantt Chart (T: trimester; see also Tables 3.1)

WG	WG TASKS		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16
WG1	T1.1																	
	T1.2																	
	T1.3																	
	T1.4																	
WG2	T2.1																	
	T2.2																	
	T2.3																	
	T2.4																	
WG3	T3.1																	
	T3.2																	
	T3.3																	
WG4	T4.1																	
	T4.2																	
	T4.3																	
	T4.4																	
WG5	T5.1	Engagement with Stakeholders																
			MC		MC		MC		MC		MC		MC		MC			MC
			GA					GA					GA					GA
	T5.2	DCP Activities																

REFERENCES

Armanhi J et al. 2016 Sci.Rep. 6,29543; Barnes E & Tringe S 2022 Biochem J. 479(3):327–335; Berg G et al 2020 Microbiome 30;8(1):103; Berg G et al 2021 Front Microbiol.12:650610; Berg G et al 2022. Environ Microb. (8):3259-3263; Berg G & Cernava T. 2022 Microbiome 26;10:54; Besset-Manzoni Y et al 2019 PLoS One 14(12) e0225655; Bonatelli et al 2021 Front. Microb.doi.org/10.3389/fmicb.2020.553223; Cammalleri et al 2020 JCR Report doi:10.2760/597045; Cellini A et al 2021 Trends in Plant Sci, 26(9):968–983; Cernava T & Berg G 2022 Environ Microbiol 24(8):3259-3263; Chen et al 2022 Microbiome 10,36. doi.org/10.1186/s40168-022-01236-9; Clouse K & Wagner M 2021 Front Bioeng Biotechnol. doi:10.3389/fbioe.2021.567548; Corbin K, et al 2020 Front Microbiol.11:937doi:10.3389/fmicb.2020.00937. Costa Santos et al 2021 Horticulturae, 2021,7(2):1–14, doi. 10.3390/horticulturae7020024; De Souza et al 2020 Front. Plant Sci. 27, doi.org/10.3389/fpls.2020.01179; Delgado L & Andersson A 2022. Microbiome 10,72 doi.org/10.1186/s40168-022-01259-2; FAO 2015.ISBN-978-92-5-108998-9; Gao M et al 2021 Microbiome 9(1):187 doi:10.1186/s40168-021-01138-2; Herrera-Paredes et al 2018 PLoS Biol.16:e2003962; Ji L et al 2022 Int. J. Mol. Sci. 23, 10427; Kazan K & Lyons R. 2014 Plant Cell.26:2285-2309. Kehe J et al. 2019. Acad Sci USA 116,12804–09; Keshavarz-Tohid et al 2017 Res Microb.168(8):760-772; Kusstatscher P et al 2021 Front Plant Sci. doi:10.3389/fpls.2021.642027; Lobanov et al 2022. Front. Microb. doi.org/10.3389/fmicb.2022.848057; Lyu et al 2021 Microorganisms 2021,9(5),1036; Olmo R et al 2022 Front Microbiol. 13:834622; Pérez-Jaramillo et al., 2016 Plant Mol Biol 2016 90(6):635-44; Rodriguez R & Duran P 2020 Front. Bioeng & Biotechn.

doi.10.3389/fbioe.2020.00568/full; Sharma et al 2022 Front. Agron., doi.org/10.3389/fagro.2021.725804; Shayanthan et al 2022 Front. Agron doi.org/10.3389/fagro.2022.896307; Silva et al 2019 Sci. Total Envir, 653, 25:1532-1545, Toju H et al. (2018). Nat. Plants 4, 247–257; Valente J et al 2020. Plant, Cell & Environ, 43(1), 246-260. Vorholt, J 2017. Cell Host Microbe 22, 142–155; Wang et al 2021 J. of Int. Plant Biol. 63 (6): 1021-1035; Zancarini et al 2021 Current Opinion in Biotech. 70:255-261